Jacobs Challenging today. Reinventing tomorrow.

Ten Years of Optimization of the Environmental Restoration Program at a DoD Facility in North Carolina

DCHWS Seminar

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Jacobs Challenging today. Reinventing tomorrow.

Presenters

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Agenda

1. Facility background
2. Environmental restoration program (ERP) and contract framework
3. Remediation optimization at eight sites
4. Optimization via green and sustainable remediation (GSR)

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Facility Background

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Facility Background

- Large federal facility in North Carolina active since 1940s
- CERCLA investigations and remediations underway since mid-1990s
- Nearly 50 active environmental sites
  - Chlorinated solvents
  - Munitions and unexploded ordnance
  - Emerging contaminants

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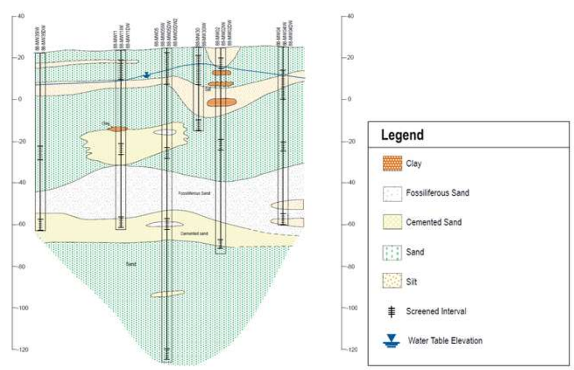
Facility Background

- Environmental and geographical setting
  - Located along Atlantic Ocean
  - Within coastal plain of southeastern North Carolina
  - Topography traversed by swales, wetlands, streams and creeks
  - Includes upland forests, wetlands, water, and urban/developed land
- Geology and hydrogeology
  - Sedimentary sequence mantles crystalline bedrock
  - Seven aquifers and their associated confining units



Typical Cross-Section

Source: USGS

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Facility Background

- Environmental impacts to soil and groundwater resulting from historical operations, storage, and disposal practices
- Areas of concern potentially causing threats to human health and the environment identified in 1981

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ERP and Contract Framework

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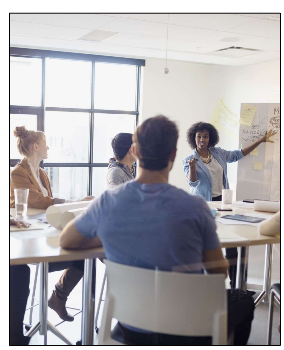
Environmental Restoration Program

- ERP started in 1986
  - Following enactment of Superfund Amendments and Reauthorization Act legislation
- Federal Facilities Agreement created in 1991 between the Federal Government, the North Carolina Department of Environment, Health, and Natural Resources (now NCDEQ), and the United States Environmental Protection Agency (EPA)
  - Ensure potential environmental impacts associated with past and present activities at the facility are investigated and appropriate CERCLA response actions are developed and implemented as necessary to protect public health, welfare, and the environment
  - Establish a procedural framework and a schedule for developing, implementing, and monitoring appropriate response actions at the facility
  - Encourage public participation and to facilitate cooperation and exchange of information among parties associated with the investigation and remediation process

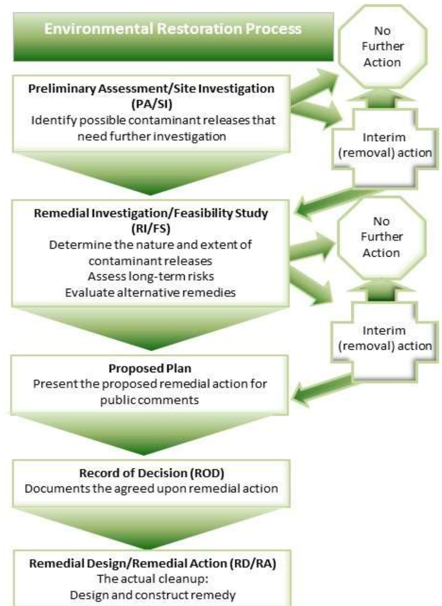
Environmental Restoration Program Partnering

- **Mission:** Work together as a team with a commitment to continuous improvement to clean up hazardous waste sites with the appropriate use of innovative, quality, and cost-effective technologies to protect human health and the environment
- Members
  - Consensus members
    - Federal government
    - NCDEQ
    - USEPA
  - Non-consensus members
    - Contractors
- Meets regularly to facilitate decision-making and expedite work
  - 12-week cycles



Contract Framework

- Jacobs' contract
  - CERCLA steps from Preliminary Assessment/Site Inspection (PA/SI) through the Remedial Design (RD)
  - Treatability studies and pilot studies
  - Long-term monitoring and optimization
- Remedial actions implemented by others
  - Remedial Action Contractor (RAC)



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Long-Term Monitoring (LTM) at Sites with Remedy-in-Place

- LTM program includes 18 sites
  - Objectives:
    - Evaluate presence and migration of contaminants
    - Evaluate effectiveness of selected remedies
    - Evaluate progress towards meeting cleanup levels
  - Media:
    - Groundwater
    - Surface water
    - Sediment
    - Pore Water
  - Analytical suites
    - Volatile organic compounds (VOCs)
    - Semi-volatile organic compounds (SVOCs) and polycyclic aromatic hydrocarbon (PAHs)
    - Metals
    - Pesticides
    - Natural attenuation indicator parameters
  - Frequency:
    - Quarterly
    - Semiannual
    - Annual
    - Biennial
    - Every 5th year

Annual Cost: ~$1,000,000

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Questions?

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Remediation Optimization at Eight Sites

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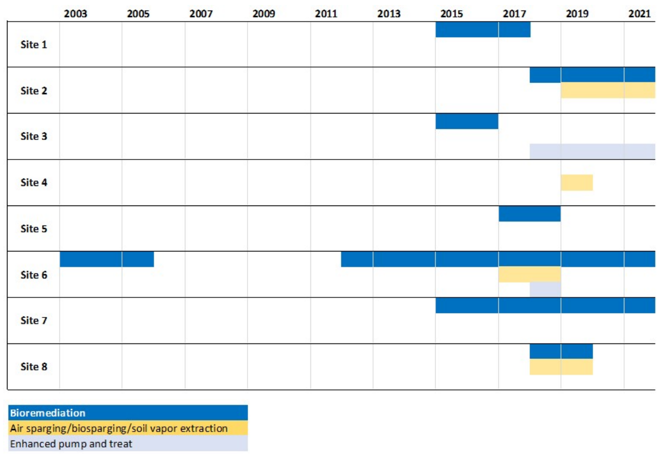
Optimization Strategy

- Proactively optimize long-term monitoring (LTM) to minimize remediation timeframes and reduce life cycle costs
  - Implementation of innovative technologies
  - Focused treatment to accelerate mass removal
  - Optimization of monitoring program

Pilot Studies by Site and Date Conducted



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Site #1 Background

- Historical use
  - Former creosote plant
    - Operated from 1951 to 1952 to supply treated lumber during construction of the railroad
- Constituents of concern (COCs)
  - PAHs in soil and groundwater

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Site #1 Remediation History

- Soil removal
  - Excavation in 2000
    - 3,300 tons of SVOC-impacted soil
- LTM and land use controls (LUCs)
  - Initiated in 1997

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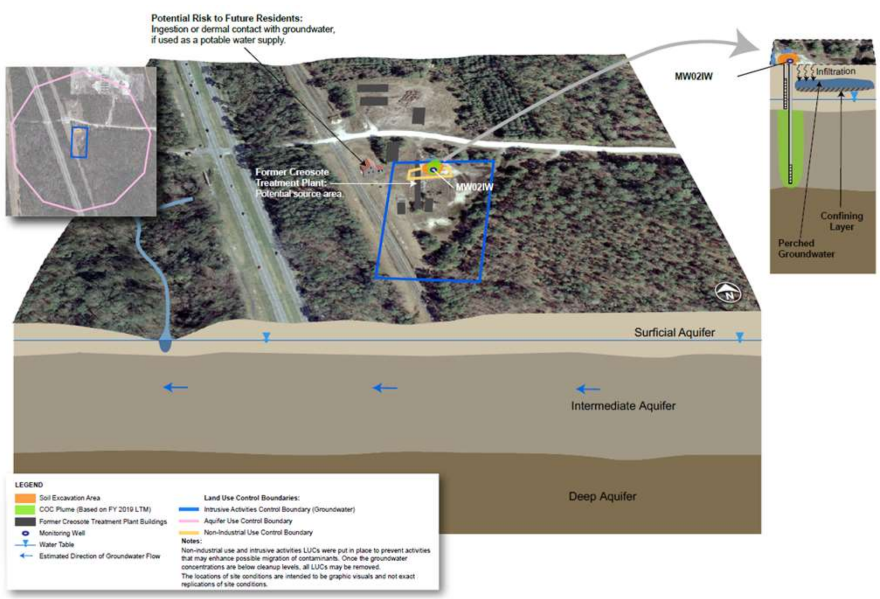
Site #1 Conceptual Site Model



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Site #1 Remediation Optimization

- Rationale
  - Stalled attenuation of PAHs
- Approach
  - Direct push technology (DPT) injections of a slow-release oxygen product in surficial aquifer and placement of oxygen substrate-filled socks in intermediate aquifer
  - Enhance oxygen substrate distribution by extracting groundwater to create a gradient towards treatment area
- Results
  - No COCs detected at concentrations exceeding North Carolina Groundwater Quality Standards (NCGWQS) in surficial aquifer
  - COCs continue to fluctuate around NCGWQS in intermediate aquifer

PAH	NCGWQS (µg/L)
Benzo(a)anthracene	0.05
Benzo(b)fluoranthene	0.05

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Site #1 Remediation Optimization

- Outcomes
  - Surficial aquifer removed from LTM program
  - Decreased LTM sampling frequency from annually to every 5 years
- Cost implications
  - Total spent: $148,000
  - Savings for removing surficial aquifer from LTM:
    - Annual cost = $6,000
    - Life cycle cost (LCC) savings (over 30 years) = $180,000
  - Savings for optimizing LTM frequency:
    - Average annual savings = $17,600
    - LCC savings (over 30 years) = $528,000

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Site #2 Background

- Historical use
  - Former fuel farm
    - Five 15,000-gallon aboveground storage tanks (ASTs), transmission lines, pump house, unloading pad, oil-water separator and distribution island
    - Active from 1945 to 1995
  - Vehicle maintenance garage
  - Weapons cleaning area
- COCs
  - Chlorinated VOCs in groundwater

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Site #2 Remediation History

- Air sparging (AS) via horizontal directionally drilled (HDD) well
  - Operated from August 2010 to February 2013
    - Shutdown milestones achieved:
      - 71% total VOC reduction in source area wells
      - 75% total VOC reduction in intermediate aquifer wells within 100 feet
      - Modeling indicated concentrations protective of surface water receptor
- Monitored natural attenuation (MNA)
  - Initiated for areas beyond influence of AS system in 2011
  - Upon system shutdown, MNA network optimized
- LUCs
  - Implemented in 2010

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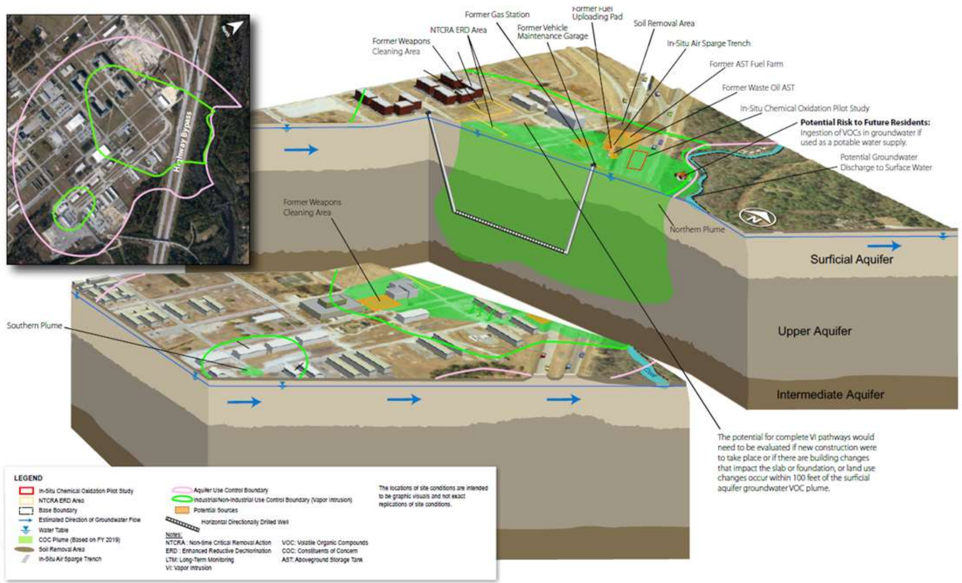
Site #2 Conceptual Site Model



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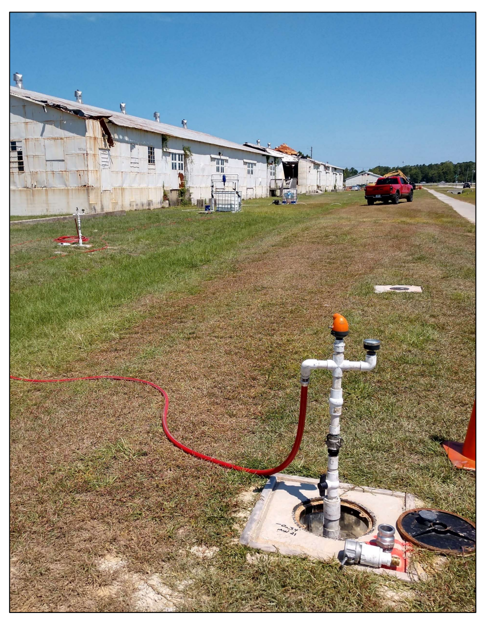
Site #2 Remediation Optimization

- Rationale
  - Stalled attenuation of trichloroethene (TCE) in southern intermediate aquifer plume
  - Residual vinyl chloride (VC) concentrations remain above NCGWQS
- Approach
  - Enhanced reductive dechlorination (ERD) via injection of emulsified vegetable oil (EVO), red yeast rice (to mitigate methane production), and microbes
    - Injection volume supplemented with site groundwater
  - Restarted HDD AS to evaluate VC degradation or rebound



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Site #2 Remediation Optimization

- Results
  - ERD
    - No apparent reduction of TCE concentrations
    - Analytical results and field observations indicate poor delivery of substrate to target wells
      - EVO observed at monitoring well 250 feet from injection area, with no apparent preferential pathway identified
  - AS
    - In progress
    - Initial sampling results indicate VC concentration reductions
- Cost implications
  - Total spent: $158,000

Ongoing Optimization Activities:
- Restarting HDD AS well to address residual COCs

Site #3 Background

- Historical use
  - Dump Area from 1940s to 1950s
    - 5 acres
    - Used for disposal of municipal waste and mixed industrial wastes
      - Trash, waste oils, solvents, and hydraulic fluids
      - Mostly burned and buried
- COCs
  - Lead, PAHs, and pesticides in soil
  - VOCs in groundwater

Site #3 Remediation History

- MNA
  - Initiated for groundwater in 2005
- LTM of surface water
  - Initiated in 2005
- LUCs
  - Implemented in 2005
- Buried waste remains in place

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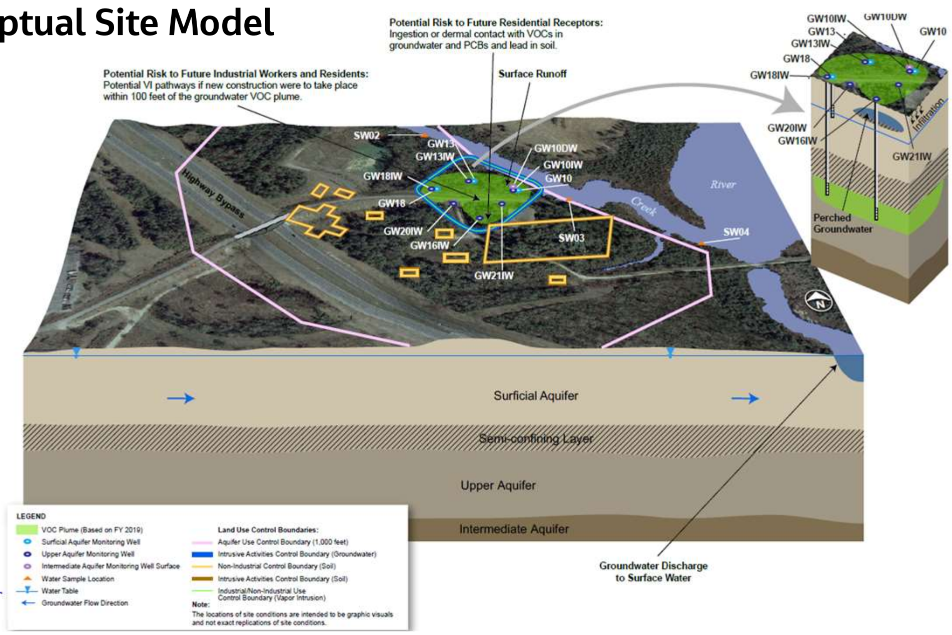
Site #3 Conceptual Site Model



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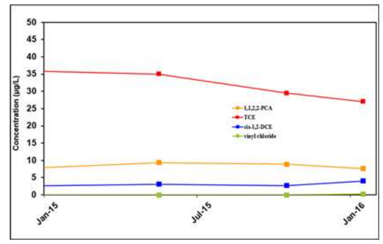
Site #3 Remediation Optimization

- Rationale
  - Stalled attenuation of 1,1,2,2-tetrachloroethane, TCE, and VC in intermediate aquifer
- Approach
  - ERD via DPT injection of EVO, red yeast rice, and microbes
- Results
  - Parent compound concentrations reduced by 50 to 80%
  - Daughter product concentrations remained stable
  - Biodegradation may be limited by low COC concentrations



Site #3 Remediation Optimization

- Outcomes
  - Decreased LTM sampling frequency from biennially to every 5 years
- Cost implications
  - Total spent: $95,000
  - Savings for optimizing LTM frequency:
    - Average annual savings = $6,600
    - LCC savings (over 30 years) = $198,000

Site #4 Background

- Historical use
  - Small dump
    - Unknown operation dates
    - Use for paint cans suspected
- COCs
  - VOCs in groundwater and pore water

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Site #4 Remediation History

- MNA
  - Initiated in 2014
- LUCs
  - Implemented in 2014

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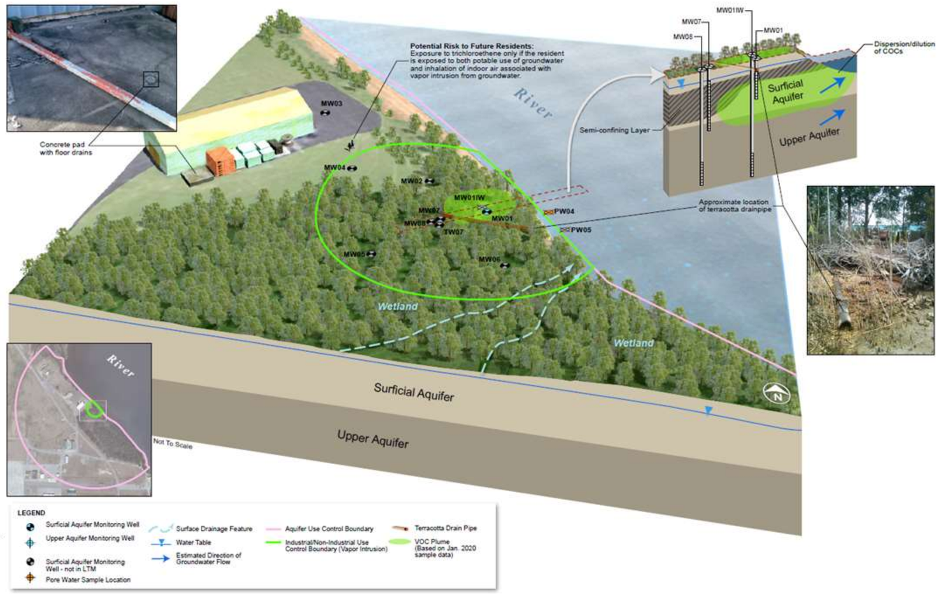
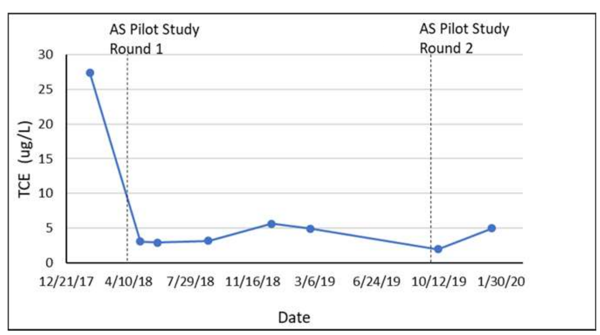
Site #4 Conceptual Site Model



Site #4 Remediation Optimization

- Rationale
  - Slower attenuation of TCE and VC in surficial aquifer than anticipated
- Approach
  - Short-duration AS below localized clay unit; used existing wells
    - Two one-week long air injection events
- Results
  - TCE and VC concentrations decreased below NCGWQS, then increased three to six months after AS



Site #4 Remediation Optimization

- Outcome
  - Proof of concept: AS effective below clay lens
  - Implement a more robust AS approach to achieve NCGWQS
- Cost implications
  - Total Spent: $78,000
  - Full-scale AS projected Cost: $224,000
  - Potential savings for site closure:
    - Average annual savings = $10,000
    - LCC savings (over 30 years) =$300,000

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Site #5 Background

- Historical Use
  - Vehicle maintenance facility
    - Active since 1946
    - Includes 10 underground storage tanks (USTs) containing various petroleum hydrocarbon products
    - Site fluids (motor oil, battery acid) reportedly discharged to ground surface
    - Use of other hazardous substances, like chlorinated solvents, disposed of in area
- COCs
  - Petroleum hydrocarbons in soil
  - Chlorinated VOCs in groundwater

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Site #5 Remediation History

- AS via HDD well
  - Operated from October 2010 to March 2012
    - Shutdown milestones achieved:
      - Cleanup levels for TCE were met within 100 feet
- Downgradient biobarrier
  - Carbon substrate and microbial culture injected via 17 vertical wells
    - Initial injection: 2011
    - Replenishment: December 2013 and August 2019
- LTM and LUCs
  - Initiated in 2010

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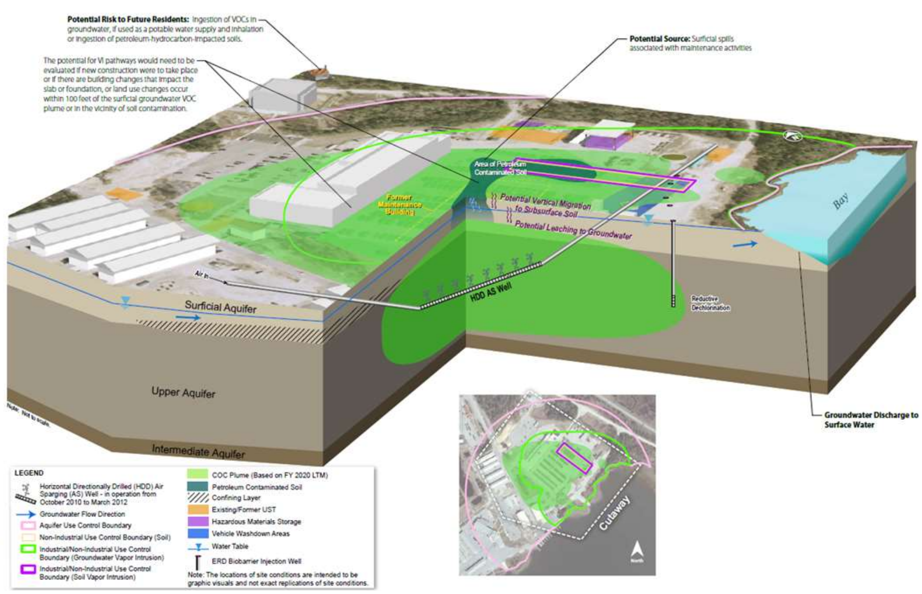
Site #5 Conceptual Site Model



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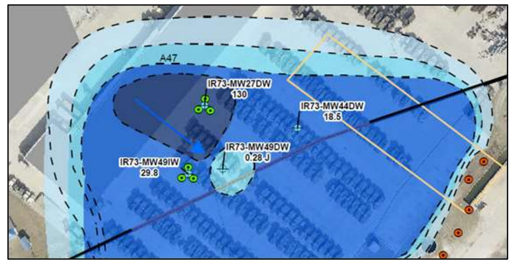
Site #5 Remediation Optimization

- Rationale
  - VC remains in source area at elevated concentrations
- Approach
  - Use BioTraps to select approach
    - Bioaugmentation alone and biostimulation with bioaugmentation successfully reduced VC concentrations
  - Bioaugment by injecting microbes and anaerobic chase water in intermediate aquifer
- Results
  - Geochemical conditions indicated reducing conditions
  - Ethene observed, indicating that reductive dechlorination is occurring
  - Bioagumentation did not significantly reduce VC concentrations in the intermediate aquifer
    - Distribution uncertainty



Ongoing Optimization Activities:
- Groundwater recirculation to rejuvenate the biobarrier
- Restarting HDD AS well to address residual COCs, including testing of warm air injection

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Site #5 Remediation Optimization

- Outcomes
  - Implement AS via HDD well to accelerate remediation timeframe
- Cost implications
  - Total spent: $114,000
  - AS projected cost: $300,000

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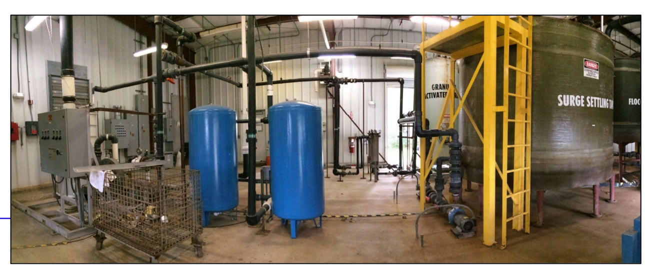
Site #6 Background

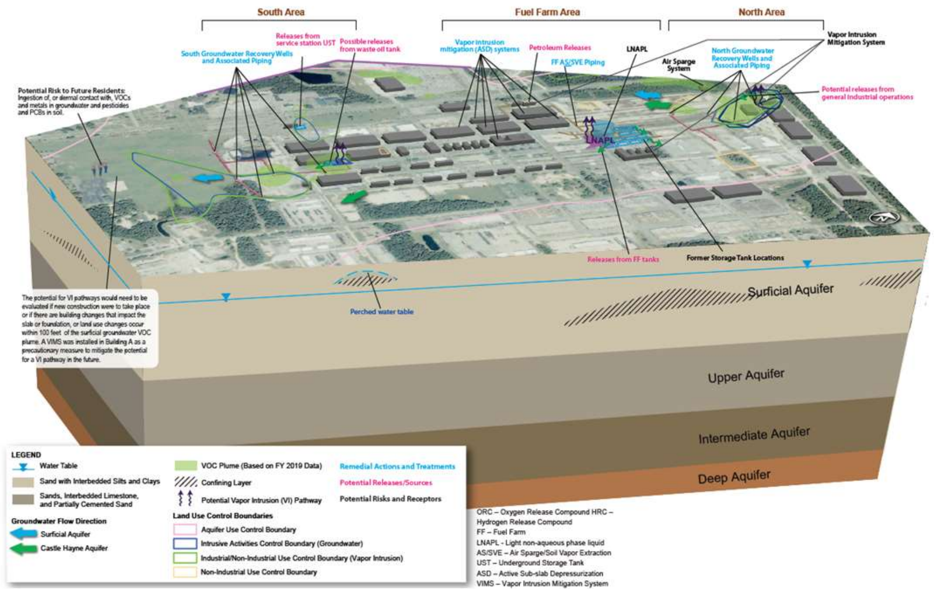
- Historical use
  - Maintenance shops, warehouses, painting shops, printing shops, auto body shops and other small industrial facilities
  - Spills and leaks of petroleum-related products and solvents from USTs and drums
- COCs
  - Polychlorinated biphenyls (PCBs) and pesticides in soil
  - VOCs in groundwater

Site #6 Remediation History

- Soil removal
  - Excavation to industrial criteria in 1995
    - 650 tons of pesticide-contaminated soil
    - 161 tons of PCB-contaminated soil
- Groundwater extraction and treatment systems
  - Two systems began operation in 1994, expanded in 1996
  - 15 recovery wells screened in surficial and intermediate aquifers
- Vapor intrusion mitigation system (VIMS)
  - Sub-slab depressurization system installed in 2012
- LTM and LUCs
  - Initiated in 1994
- Five Year Review
  - Concluded that remedy is not functioning as designed (2015)
    - New source areas discovered
    - Contamination present in deeper aquifers
    - Mass removal asymptotic
- Feasibility Study (FS) amendment investigations underway (2017 – present)



Site #6 Conceptual Site Model



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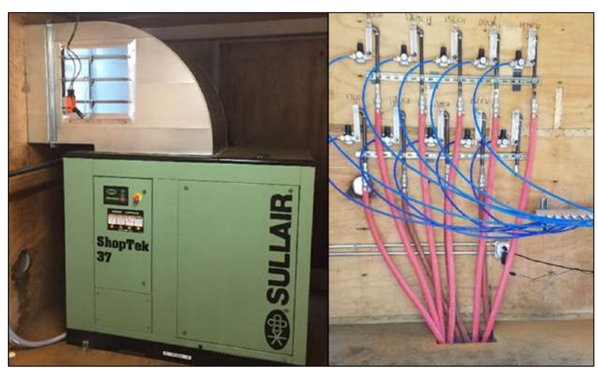
Site #6 Remediation Optimization

- Objective
  - Evaluate technologies identified in draft FS that could replace pump and treat
- Rationale
  - Elevated concentrations (~19,000 µg/L) of chlorinated VOCs outside of the influence of the pump and treat system
- Approach
  - AS in nested wells to treat contaminants present at depths up to 125 feet below ground surface (bgs)



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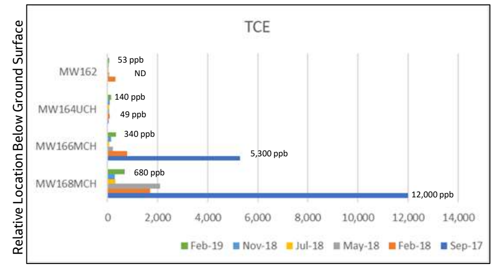
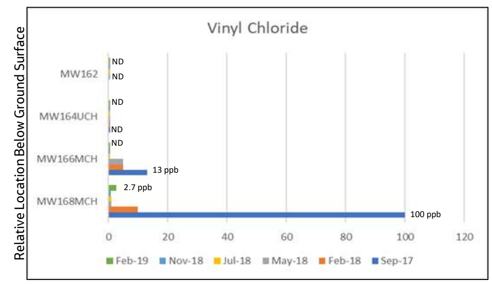
Site #6 Remediation Optimization

- Results
  - Overall, chlorinated VOC concentrations decreased
    - TCE decreased by up to 94%
    - Cis-1,2-DCE decreased by up to 99%
    - VC decreased by up to 98%
  - Approximately 50 pounds of chlorinated VOC mass removed during sparging
  - Accumulation not observed in surficial or intermediate aquifers
  - Some rebound observed 3-months post-treatment
    - Likely a result of advection from upgradient contamination rather than desorption





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Site #6 Remediation Optimization

- Outcome
  - Proof of concept: AS at depth
  - Reduced chlorinated VOC concentrations allows for consideration of MNA instead of active treatment
- Cost implications
  - Total spent: $450,000
  - Potential savings for selecting MNA instead of active treatment:
    - LCC of MNA = $290,000
    - LCC of active treatment = $4.5M
    - Savings with MNA = $4.2M

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Site #7 Background

- Historical use
  - 550-gallon UST
    - Stored waste oil
    - Removed in 1993
- COCs
  - Chlorinated VOCs in groundwater

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Site #7 Remediation History

- In situ chemical oxidation (ISCO)
  - Permanganate injection for source treatment from 2006 to 2007
    - 236,000 gallons of permanganate solution injected
      - 60% of design volume
      - Injections challenged by elevate water table and low flow rates
- MNA
  - Initiated in 2008 upon completion of permanganate injections
- LUCs
  - Implemented in 2009

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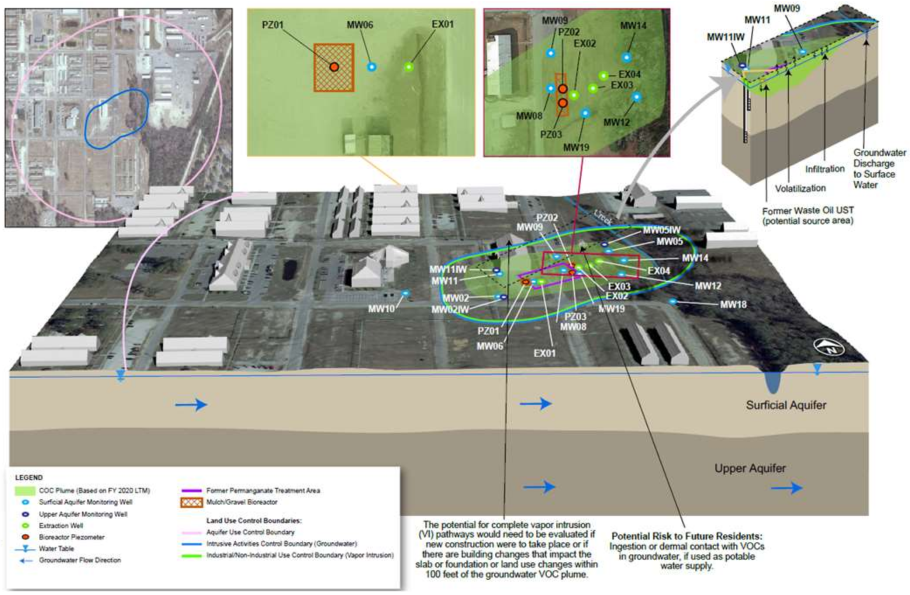
Site #7 Conceptual Site Model



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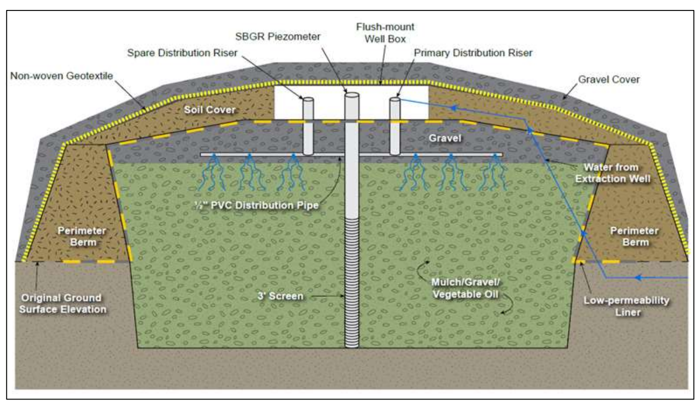
Site #7 Remediation Optimization

- Rationale
  - Slower attenuation of CVOCs in than anticipated
- Approach
  - Installed solar-powered subgrade biogeochemical reactor (SBGR)
- Results
  - Created conditions conducive for reductive dechlorination
  - Decreasing parent compounds concentrations and increasing daughter product concentrations



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Site #7 Remediation Optimization

- Outcomes
  - Reduced time to cleanup by 50 years
  - Conduct an expanded study by installing a second SBGR to reduce downgradient COC concentrations
- Cost implications
  - Total spent (expected): $585,000
  - Cost savings associated with accelerated time to site closure:
    - Average annual savings = $25,000
    - LCC savings (over 50 years) = $1,250,000

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Site #8 Background

- Historical use
  - 300-gallon waste oil UST
    - Removed in 1997
- COCs
  - Chlorinated VOCs in groundwater and soil vapor

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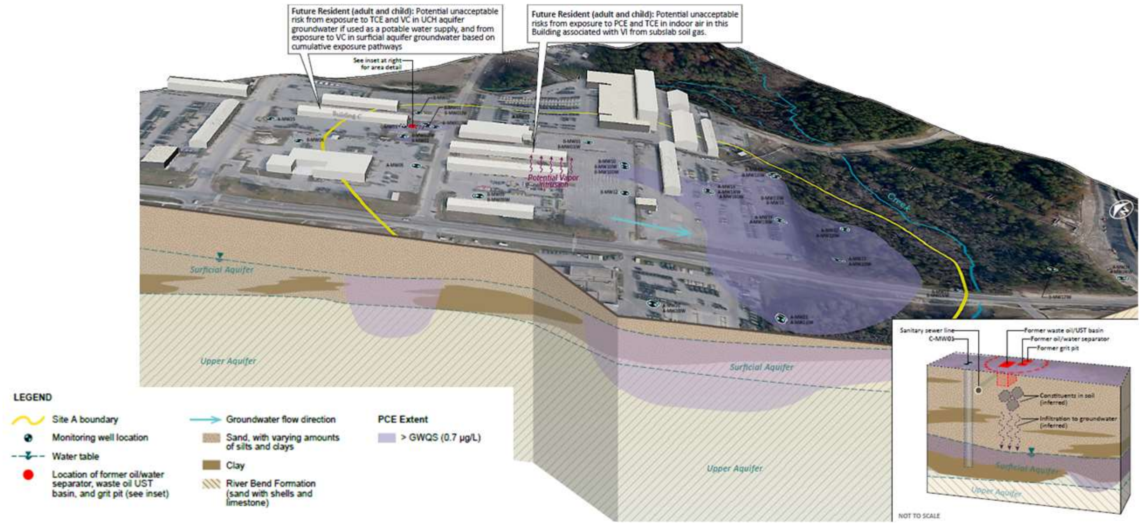
Site #8 Conceptual Site Model



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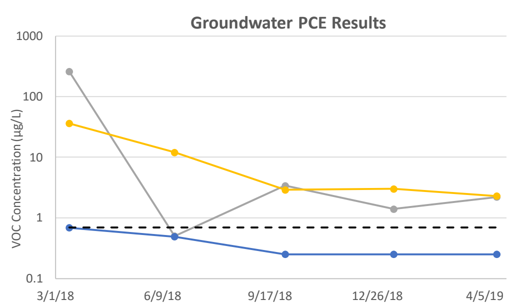
Site #8 Remediation Optimization

- Pilot study conducted prior to FS
  - ERD via DPT injection of EVO
  - Solar-powered SVE system operated for 12 months
- Outcomes
  - Reduced elevated concentrations sufficiently for selected remedy to be MNA and not active treatment
- Cost implications
  - Total spent: $150,000
  - Cost savings: $5.25M



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Optimization Summary

- DoD has invested $2.3M at eight sites to evaluate remedial technologies
  - Benefits include shorter remediation timeframes and reduced LCCs
    - $12M estimated LCC savings
- Technology lessons learned
  - AS effective for treatment of chlorinated VOCs to remediation goals
  - Injection scenarios challenged by heterogeneities
  - Biodegradation may be limited by low COC concentrations and ERD may not be effective

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Optimization Summary

Site	Initial Investment	Initial COC Concentration (µg/L)	Final COC Concentration (µg/L)	Reduced Remediation Timeframe (years)	Cost Savings
1	$148,000	0.227	0.134	--	$708,000
2	$158,000	49.9	38	--	TBD*
3	$95,000	44.75	19.10	--	$198,000
4	$302,000	28.5	3.34	30	$300,000
5	$414,000	130	170	--	TBD*
6	$450,000	19,100	1,263	--	$4,200,000
7	$585,000	235	199.75	50	$1,250,000
8	$150,000	~300	<5	--	$5,250,000
	$2,302,000				$11,906,000

*Optimization is ongoing and potential savings may be realized.

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Questions?

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Optimization via GSR

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Standard Guide for Greener Cleanups

- The act of cleanup creates its own environmental impacts
  - Energy requirements
  - Air pollution
  - Water use
  - Material production/waste disposal
  - Land and ecosystem impacts
- Standard provides process for identifying, evaluating, incorporating, and documenting best management practices (BMPs) during cleanup

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Best Management Practice (BMP) Process

- Opportunity assessment
- Prioritization
- Selection
- Implementation
- Documentation
  - For each cleanup phase
  - Public submittal

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BMP Summary

- 20 BMPs implemented
- All phases of site work

Attachment 1. Greener Cleanup BMP Table

Category	Best Management Practice	Required by Local, State, or Federal Law	Excluded? (If yes, rationale included)	Implementation Details	Core Element Addressed (at Site Level)					Remediation Technology											
					Energy	Air	Water	Materials and Waste	Land and Ecosystems	Soil Vapor Extraction	Air Sparging	Pump and Treat	In situ Chemical Oxidation	Bioremediation/MNA	In situ Thermal Treatment	Phytotechnology	Subsurface Containment and Treatment Barriers	Excavation and Surface Restoration	Ex situ Bio/Chemical Oxidation	Landfill Covers and Caps	Vapor Intrusion Mitigation
Buildings	Reuse existing structures for treatment system, storage, sample management, etc.	No	No	AS system conex box was moved to	X			X	X	X	X	X									
Materials	For ISTT using ERH, co-locate electrodes and recovery wells in the same borehole, particularly in the saturated zone, to minimize the total number of wells and land disturbance	No	Yes, technology screened out during the FS.	Not implemented.	X	X	X	X	X						X						
Materials	For ISTT, when insulating the surface of the TTZ to reduce energy losses, use greener insulation alternatives such as LECA beads (rather than polyurethane foam)	No	Yes, technology screened out during the FS.	Not implemented.	X			X							X						
Materials	For landfill covers, use minimum slope while maintaining proper drainage to reduce the volume of fill	No	No	Remedial Design specified a minimum slope of 5% and a maximum slope of 33% to maintain drainage while minimizing				X	X									X		X	

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Example: SBGR at Site #7

- Applicable BMPs
  - Bio-based materials (soybean oil)
  - Uncontaminated site soil for backfill
  - Solar powered pump
- Impacts
  - Reduced landfill waste and greenhouse gas emissions
  - Maximized use of renewable energy
  - Reduced concentrations in source area and potential time to site closure

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Example: AS at Sites #2 and 5

- Applicable BMP
  - Set milestones for system shut down
- Impacts
  - Savings of ~800,000 kilowatt hours per system per year per system
  - Reduced cost and green house gas (GHG) emissions associated with electricity production

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Example: LTM Program at Various Sites

- Applicable BMPs
  - Worked with regulator to remove minimum purge volume requirement
- Impacts
  - Approximately 400 wells sampled per year
  - Approximately 2,000 gallons of purge water avoided/year
    - Approximately 40 55-gallon drums

Annual Reductions		
GHG Emissions (metric tons)	Energy Used (MMBTU)	Cost
1.1	15	$7,000

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Example: LTM Program at Various Sites

- Applicable BMPs
  - No purge technology, 300 wells/year
  - Optimized well network and utilized existing wells
    - PDBs, Hydrasleeves, and snap samplers
- Impacts
  - Minimized waste management
    - Avoided ~4,500 gallons aqueous waste/year
    - Eliminated need for ~45,000 feet of tubing/year
  - Reduced greenhouse gas emissions related to transportation
  - Reduced time and cost

Annual Reductions		
GHG Emissions (metric tons)	Energy Used (MMBTU)	Cost
↓ 2.4	↓ 36	↓ $32,000

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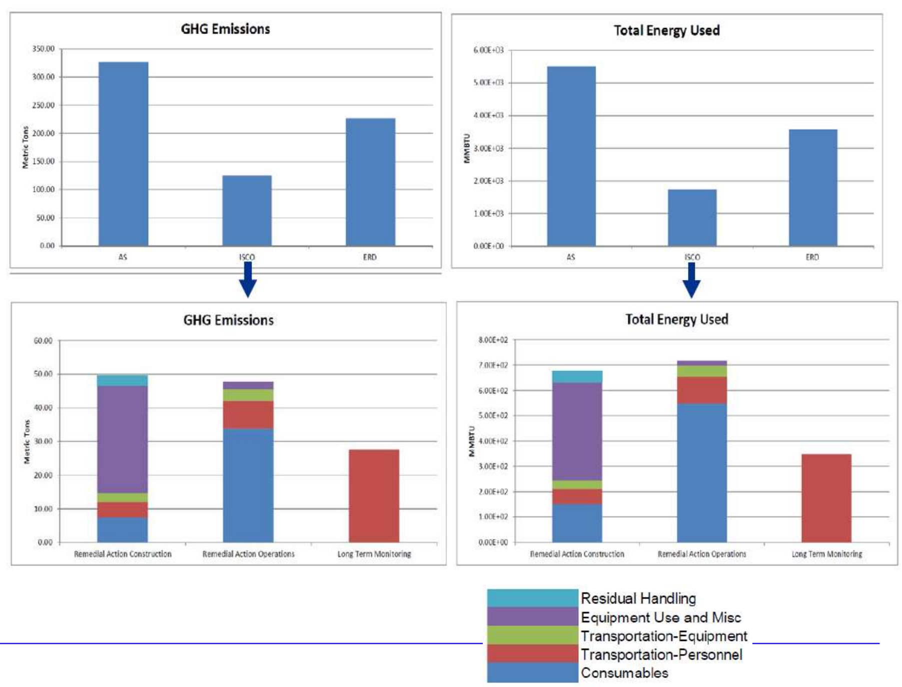
SiteWise Analysis

- Remedy selection
  - Compare alternatives in terms of a consistent set of sustainability metrics
- Remedy implementation
  - Identifies opportunities to reduce footprint during design



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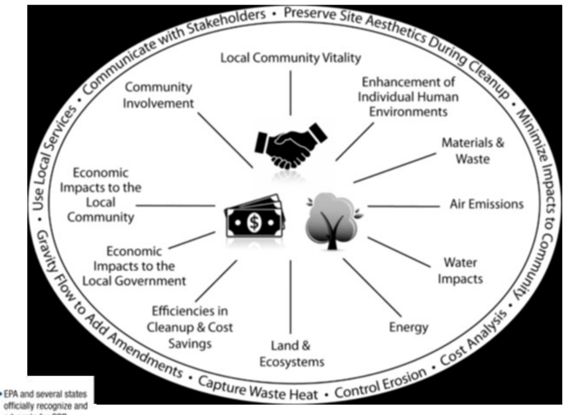
Benefits of GSR During Optimization

- Optimize existing remedies to reduce time, cost, and environmental impacts of cleanup
- Minimize environmental impacts for future cleanup actions
- Establish a culture of green sustainable remediation
- Trigger “The Virtuous Cycle”



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Pulling It All Together

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Key Takeaways

- LTM sites can be proactively optimized to minimize remediation timeframes and reduce LCCs
  - Implementation of innovative technologies
  - Focused treatment to accelerate mass removal
  - Optimization of monitoring program
- Optimization includes consideration of sustainability metrics and BMPs to reduce the environmental impacts of the cleanup action
- Cooperation and consensus building with stakeholders facilitates optimization efforts and streamlines the realization of efficiencies

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Thank you

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